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FINAL TECHNICAL REPORT
for
INFORMATION AND STOCHASTIC SYSTEMS
ONR CONTRACT N00014-89-J-1175
01 November 1988 - 30 June 1992

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September 30, 1992

SUMMARY

Principal results obtained during the contract period were in the following areas:

- 1) Information capacity of stationary Gaussian channels;
- 2) Information capacity of Gaussian channels subject to jamming;
- 3) Capacity of Poisson and Poisson-related channels;
- 4) Coding capacity of dimension-limited channels;
- 5) Absolute continuity and channel capacity for problems involving Gaussian-mixture noise;
- 6) Further development of new algorithms for signal detection;
- 7) Computational evaluation of both new and classical algorithms for detection of signals in noise, with comparisons and results;
- 8) Analysis and modeling of passive sonar data;
- 9) Representation of stochastic processes.

Two of the PI's students received the Ph.D. in Statistics during this period; both were supported in part by grant funds. In addition, five other graduate students received some financial support from the grant, primarily for work associated with the computational work on tasks 7) and 8) above.

As can be seen from the above list of topics, and more clearly from the remaining parts of this report, the principal thrust of the research carried out under the grant has been on capacity of noisy communication channels and on nonGaussian signal detection problems. Our work has differed from all other work known to us in two respects:

- a) For channel capacity, our emphasis is on general continuous-time channels or infinite-dimensional discrete-time channels;

- b) For signal detection, we emphasize a rigorous mathematical solution of the underlying continuous-time problem, develop discrete-time algorithms based on those solutions, then computationally evaluate the algorithms using both simulated data and experimental data obtained from operational systems.

So far as we know, all work published during the past 15 years in these two areas which has all of the above characteristics has emanated from our research program. This includes work not only by the PI, but by his students and by a number of colleagues in Japan and Europe. The research supported by this grant has continued the previous work, and the continuity of funding provided by ONR has been extremely important in enabling us to obtain the results described below.

The results in each of the nine areas listed above are very briefly described in the next section.

DISCUSSION OF MAIN RESULTS

1. Information Capacity of Stationary Gaussian Channels [15].

This is one of the principal areas of research in the Shannon theory. A partial solution was obtained in [1]. The solution obtained in our work [15] is far more general. For Gaussian channels having noise with rational spectral densities, our results provide a complete solution to the information capacity problem. This includes an independent proof of the results of [1] for noise having a rational spectral density.

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2. Information Capacity of Gaussian Channels Subject to Jamming [8], [9].

The channels considered in this work are "matched"; in the absence of jamming, the constraint on the transmitted signal is given in terms of the noise covariance. Our interest is primarily in channels with memory, especially infinite-dimensional channels (e.g., continuous-time channels with memory).

One result obtained in this work is that use of a jammer constraint commonly employed in engineering analysis of finite-dimensional channels is too strong to be meaningful when used for the infinite-dimensional channel: the jammer cannot decrease the capacity of the channel, regardless of his available energy. A more realistic constraint on the jammer was determined, and, as this constraint was not previously applied in previous published work, the jamming problem was solved for both finite-dimensional and infinite-dimensional channels.

3. Capacity of Poisson and Poisson-Related Channels [11], [16].

Poisson channels are of particular interest in optical communications. The continuous-time problem was modeled and the information capacity obtained for the case of random or time-varying noise intensity. Bounds were obtained on the increase in capacity obtained with causal feedback. A class of jamming problems was considered, and the optimal jamming signal determined. Results on coding capacity were obtained. The results given in [16] provide a compact unification of several seemingly-disparate results on capacity.

4. Coding Capacity of Dimension-Limited Additive Channels [10], [13].

This work applies to communication channels where the dimensionality of the code word set is a part of the signal constraint. A complete solution of

the coding capacity problem was obtained for Gaussian channels, and upper bounds on capacity for a class of nonGaussian channels. These results contain, as special cases, solutions to coding capacity for the classical discrete-time Gaussian channel, and coding capacity for a class of continuous-time Gaussian channels.

5. Absolute Continuity and Channel Capacity for Problems involving Gaussian-Mixture Noise [17], [18].

Gaussian-mixture noise is of the form $N = AG$, where G is a Gaussian process and A is a non-negative random variable independent of G . Such a process is frequently used to model noise arising in sonar applications. In [17], the absolute continuity problem is considered: conditions for the likelihood ratio to exist between a process Y (e.g., signal-plus-noise) and a Gaussian mixture noise process N . A solution is obtained, and expressions for the likelihood ratio obtained. These results are then applied to obtain the information capacity of a communication channel perturbed by additive Gaussian mixture noise.

6. Further Development of New Algorithms for Signal Detection [14], [18].

This work was based on the mathematical results contained in [2] and [17]. A preliminary description of the algorithms for detection in Gaussian noise was given in [3]. The treatment in [18] is far more complete and includes several new results. These include, for example, algorithms for detection in Gaussian-mixture noise.

The 49-page paper [18] was solicited in 1989 for inclusion in a book to be published in 1990. The latest estimate is that the book will be published in 1993. One of the editors of this book has been Principal Investigator of

an SBIR contract on detection of nonGaussian signals in Gaussian noise (the Phase II contract now being in progress). He has commented to the PI that the development in [18] was viewed as "the most promising" approach, based on his company's Phase I survey of applicable methods. The Phase II contract is apparently an extension to arrays of the computational evaluations described in [14].

7. Computational Evaluation of both New and Classical Algorithms for Signal Detection [14].

This work involved the use of simulated data and passive sonar data. The primary objective was to obtain numerical results on performance of new algorithms described in [18] and [3], and to compare this performance with that of selected reference algorithms. In short, the new algorithms gave very good relative performance. The relative performance should increase with more realistic data sets and with progress on optimizing their parameters.

8. Analysis and Modeling of Passive Sonar Data [6], [20].

This work involved statistical testing of the passive sonar data used to carry out the evaluations described under (7) above. It was found that neither the noise nor the signal-plus-noise could be clearly accepted as Gaussian, although the degree of non-normality varied with the frequency range.

Another element of this work was the modeling of the data as a Gaussian mixture. This aspect appears to have some potential for use in classification.

This work was an extension and refinement of earlier work, reported in [20].

9. Representation of Stochastic Processes [12]. [19].

The mathematical results obtained in [2], which have provided the theoretical foundation for the promising new algorithms described in [3] and [18], are based on the spectral representation of second-order stochastic processes, and also make use of reproducing kernel Hilbert space (RKHS) theory at key points of the development.

The technical reports [12] and [19] contain a development of the applicable theory in these two areas. The RKHS report is directed toward readers interested in stochastic processes.

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